DIAGNOSTIC & IMAGING WORKSHOP

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE), Fossil Energy Office, in conjunction with the National Energy Technology Laboratory (NETL) and the National Petroleum Technology Office (NPTO), hosted a collaborative diagnostics and imaging workshop in Houston, Texas at the Hyatt Regency Houston Airport on Tuesday and Wednesday, February 27-28, 2001. The purpose of the workshop was to gather government and industry input on the diagnostic and imaging R&D needs for oil and gas exploration and production. The workshop results will be considered as DOE develops future R&D activities.

Presentations, summaries of comments on company perspectives, work group products, and a participant list are contained in the proceedings. A short background, summary results, and a DOE perspective are provided below.

Background

The Diagnostics and Imaging R&D Program is part of DOE's effort to develop and apply advances in exploration and production to the understanding and development of oil and gas resources. Advances in diagnostics and imaging could significantly enhance the finding and production of these fuels. A description of the DOE program is provided at http://www.fe.doe.gov/oil_gas/diagnostics/index.shtml. The goals of the diagnostics and imaging oil and gas programs are to support the development of technologies to detect, predict, and understand the important parameters of reservoir rocks and contained fluids that affect oil and gas exploration and production. The Federal role is coordination, integration, and synthesis of research efforts in reservoir characterization, field-testing, and modeling and risk analysis.

Results

Following presentations on current DOE and industry programs, four work-group sessions were conducted in succession.

The initial session examined the reservoir targets driving core R&D. Participants brainstormed on issues to develop a range of target reservoirs. Because the list included a large and diverse list of reservoirs, an attempt was made to group them under three major headings: lithology, others, and geological setting. Not readily apparent from the boards was the discussion on the need to improve technology transfer.

The second session examined the pending barriers and issues to locating and quantifying the resource and flow characteristics in target reservoirs. There was a strong emphasis on seismic aspects. Participants brainstormed on barriers and issues to develop a wide range of topics that were grouped under four major headings: basic physics, basic physics subgroup on seismic to fluid link, tools and techniques, and business drivers. The group strongly emphasized basic physics aspects, whereas DOE had anticipated that tools and techniques would be the major emphasis.

Based on the barriers and issues identified in the previous session, the third session identified the R&D opportunities for developing diagnostics and imaging tools and methodology to overcome these barriers and issues. Brainstorming on opportunities followed the four broad group categories previously

mentioned. The session ended by tallying the individual priorities of the most important R&D opportunities.

In the fourth and last session, participants identified specific actions and products for the top priority R&D opportunities. In addition, participants defined expertise needs, schedule aspects, and lead roles for implementation. Although only the top four R&D opportunities were scrutinized in detail, many other important opportunities were noted for consideration.

The highest ranked opportunity was to understand and overcome the limits on seismic resolution, including acquisition and processing, hardware, and sampling theory. Action focused on stimulating expert comment via a workshop and a website. Suggested products included a measuring experiment and a deep source deployment. Expertise needs cover a broad range of mathematics, physics, geophysics, information theory, rock physics, and expertise outside the gas industry. Prompt action and coordination with the Society of Exploration Geophysicists (SEG) were deemed essential.

The second priority opportunity was data fusion or integration, both static and dynamic data at multiple scales and from multiple sources, including knowledge management and visualization. The ultimate product goal is software for real-time reservoir management, simulation, and data streaming. Expertise needs cover a broad range of data management, artificial intelligence, 4D visualization, and uncertainty theory. A schedule of several years is expected. The DOE Office of Science should have the lead role with a software developer, an industry partner for data, and a service company for commercialization.

Pre-stack and elastic inversion, including 3-component data and processing framework, was combined with tools for shear wave imaging for the third priority opportunity. Numerous action and products revolve around modeling and P and S structural imaging. Wave propagation scientists, rock physicists, and mathematicians are the expertise needs. This is a long-term action of 5 to 10 years with a short-term product of a field and synthetic data set. Research and end-users should lead this effort under a collaborative partnership of DOE, SEG and industry.

The fourth and last opportunity to be analyzed was the integrated seismic-electromagnetic, single well imaging system, or DeepLook. The action involves same-system integration with case studies and perhaps cross-well seismic. A wide range of expertise is already involved, and interpreters will be needed. Within the next 6 months, a proposal is due to the DeepLook consortium for 3-year funding at approximately $800,000 per year. The DeepLook consortium is established and capable of leading this opportunity.

Next Steps

The DOE recognized many opportunities for Federal R&D in the suggestions from this workshop.

The Federal role is to:

- Deliver high-risk, long-term research in which individual companies will not invest
- Accelerate industry efforts through R&D collaboration
- Invest in technologies needed by independents who lack R&D funds
- Enhance the value of Federal lands that supply 37% of oil and 25% of oil

The DOE plans to incorporate the recommendations from this meeting in its program planning and initiate additional industry/academia workshops to get more-detailed recommendations on specific elements from this workshop. In addition, DOE will investigate cooperative efforts with the SEG in implementing R&D activities that grow out of this workshop.

DIAGNOSTIC & IMAGING WORKSHOP

CONTENTS

DIAGNOSTIC & IMAGING WORKSHOP

I. PRESENTATIONS

A. ADVANCED DIAGNOSTICS AND IMAGING SYSTEMS PROGRAM (ADIS)

Bob Lemmon
National Petroleum Technology Office

National Petroleum Technology Program

National Petroleum Technology Program: Technology Areas

Advanced Diagnostics and Imaging Systems

Emerging Processing Technology Applications

Advanced Drilling, Completion, and Stimulation

Effective Environmental Protection

Reservoir Life Extension and Management

Crosscutting Program Areas

✓218 active projects as of 9/30/2000.

National Petroleum Technology Office

Advanced Diagnostics and Imaging Systems Program (ADIS)

Bob Lemmon, Technology Manager

Project Managers

Dan Ferguson	Dan Gurney
Purna Halder	Chandra Nautiyal
Tom Reid	Ginny Weyland

February 27, 2001

National Petroleum Technology Office

ADIS Program Organization - 1

- Organizational Structure
  - Geoscientific/Engineering Measurement
    - Electrical and electromagnetic
    - Seismic tool development
    - Seismic analysis techniques
    - Well logging/monitoring
  - Reservoir Description/Characterization
    - Fracture modeling
    - Geomechanics
    - Core/pore-scale studies
    - Geostatistics
    - Basin-specific multidisciplinary studies

National Petroleum Technology Office

ADIS Program Organization - 2

- Organizational Structure
  - Reservoir Modeling and Simulation
    - Data access
    - Data preservation
    - Field laboratories
  - Oil Exploration Research
    - Basin Analysis
    - General

National Petroleum Technology Office

ADIS - Goals

- Increase accuracy and resolution of seismic and other geological and geophysical technologies - (field - to - inter well scales)
- Develop new technologies to measure in-situ reservoir fluid and rock properties - (pore - to - near wellbore scales)
- Integrate multiple technology, data sets into refined geologic and engineering models that guide oil field development and management for maximum economic oil recovery

National Petroleum Technology Office

ADIS - What are we doing?

- Research and development of multiple tools, technologies and methodologies used in various combinations to image and characterize hydrocarbon reservoir rocks and associated fluids and gases

- Developing technologies to quantify various aspects of the reservoir ranging from pore through field and even basin scales

National Petroleum Technology Office

ADIS - Why are we doing this work?

- Reservoir characterization (RC) is the underpinning for all activities targeting hydrocarbon reservoirs
- Economic success of drilling, development and production, and EOR/IOR activities is related to the (RC) knowledge base and the geologic/engineering models developed from these data
- Risk, both economic and environmental, is reduced by integrating (RC) technologies
- RC - "a life-cycle" set of activities

National Petroleum Technology Office

ADIS - Who is doing this work?

- About 60 + active ADIS projects are funded through this program area
- Projects include partnering with individuals and groups - independent and major oil companies, service companies, independent research groups, universities, national laboratories, and the Natural Gas and Oil Technology Partnership (NGOTP)
- Most projects include interdisciplinary teaming and cost-sharing

National Petroleum Technology Office

ADIS - Budget

- ADIS Budget and % of total Oil Technology Program (in millions $'s):

	FY96	FY97	FY98	FY99	FY00	FY01
ADIS	8.3	6.6	6.0	7.15	7.05	7.05
Oil Program	54.9	45.2	47.7	48.6	57.3	68.0
% of Total	15%	15%	13%	15%	12%	10%

National Petroleum Technology Office

ADIS - Budget

- Natural Gas and Oil Technology Partnership (NGOTP) - Supporting Research (SR) budget and the Diagnostics and Imaging Forum (DIT) area (in millions $'s):

	FY96	FY97	FY98	FY99	FY00	FY01
NGOTP-SR	4.7	5.4	6.5	7.4	7.4	7.4
DIT				3.1	4.4	4.4

National Petroleum Technology Office

ADIS Program Philosophies - 1

- Balance applied research vs component(s) of basic research
- Balance program contractor's strengths;
  - National Labs - engineering tool & technology development
  - Univ., governmental and private R & D centers (multi-disciplinary teamwork) - technology development, application and integration of multiple data sources into geologic and engineering models of oil reservoirs to improve oil exploration and recovery efficiencies

National Petroleum Technology Office

ADIS Program Philosophies - 2

- Target oil reservoirs/formations/basins that will allow producers to extrapolate application of technologies to other fields & possibly other basins
- Industry R & D cost-shared collaborations and partnerships for implementation of project results and technology transfer
- Balance technology evolution between tool development - ex. data acquisition, data processing and interpretation

National Petroleum Technology Office

ADIS Program Philosophies - 3

- Balance time required to bring new technologies along (longer-term) vs the need for near-term results
- Balance ADIS program area with other Oil Program areas to maximize overall benefits to the public through industry application
- Balance longer-term national needs with more near-term special interest needs
- Aggressively promote technology transfer

National Petroleum Technology Office

ADVANCED DIAGNOSTICS AND IMAGING SYSTEMS PROGRAM
FEBRUARY 23, 2001

Organizational Structure:

1.0 GEOSCIENTIFIC MEASUREMENT
- 1.1 Electrical and Electromagnetic
- 1.2 Seismic Tool Development
- 1.3 Seismic Analysis Techniques
- 1.4 Well Logging/Monitoring

2.0 RESERVOIR DESCRIPTION
- 2.1 Fracture Modeling
- 2.2 Geomechanics
- 2.3 Core/Pore-Scale Studies
- 2.4 Geostatistics
- 2.5 Basin-Specific - Multidisciplinary Studies

3.0 RESERVOIR MODELING AND SIMULATION
- 3.1 Data Access
- 3.2 Data Preservation
- 3.3 Field Laboratories

4.0 OIL EXPLORATION RESEARCH
- 4.1 Basinal Analysis

5.0 GENERAL

Organizational Structure:

1.0 GEOSCIENTIFIC MEASUREMENT

1.1 Electrical and Electromagnetic

- 00BC15307 Electromagnetic Instruments, Inc./Michael Wilt - Oil Reservoir Characterization and CO2 Injection Monitoring in the Permian Basin with Cross-well Electromagnetic Imaging
- FEW-0011 LLNL/Phil Harben - Oil Field Characterization and Process Monitoring Using Electromagnetic Methods
- FEW-0031 LLNL/Phil Harben - Steel Casing Crosshole Electromagnetic Imaging
- P-23 LBL-Partnership/Ki Ha Lee Extending Borehole Electromagnetic Imaging to Cased Wells (funded under the OGRT forum)

1.2 Seismic Tool Development

- FEW-2836.6 SNL-Partnership/Bob Cutler - Development of a 3-Component Borehole Seismic Source
- P-24 - LANL/LLNL-Partnership/James Albright - Advanced Sensor Technology for Microborehole and other Seismic Applications/Microborehole Seismic Instrumentation
- P-40 LLNL-Partnership/Christian Simonson - Acquisition of Borehole Seismic Data Behind Production Tubing/Reducing Certain Seismic Data Acquisition Costs Through Shaped Charges
- P-44 - SNL-Partnership/Robert Cutler - Development of Single Well Imaging Systems
- P-45 LBL-Partnership/Ernie Major - Development of Single-Well Seismic Imaging Technology
- P-205 - LANL-Partnership/Robert Peters - Next Generation Seismic Modeling and Imaging
- ACTI-003 INEEL/SNL-Partnership/Dave Weinberg - Large Downhole Seismic Sensor Array
- ACTI-053 - LANL-Partnership/Michael Fehler - Improved Prestack Kirchkoff Migration for Complex Structures/Seismic Imaging of Complex Terrain (Gulf of Mexico Subsalt Project)
- ACTI-074 - LLNL-Partnership/Fred Followill - Vertical Seismic Profiling While Drilling

1.3 Seismic Analysis Techniques

- 00BC15301 Virginia Polytechnic Institute & State Univ./Matthias Imhof - Seismic Determination of Reservoir Heterogeneity: Application to the Characterization of Heavy Oil Reservoirs
- 00BC15302 Univ. of Oklahoma/Thurman Scott - Accoustical Imaging and Mechanical Properties of Soft Rock and Marine Sediments
- 01SW53227 Stanford Univ./Amos Nur - Stanford Rock Physics and Borehole Geophysics Consortium
- 98BC15135 Michigan Technology Univ./Wayne Pennington - Calibration of Seismic Attributes for Reservoir Characterization
- ACTI-009 LANL/LLNL/ORNL-Partnership/Leigh House - Testing Advanced Computational Tools for 3D Seismic Analysis Using the SEG/EAEG Model Data Set
- P-103 LBL-Partnership/Kurt Nihei - Frequency Dependent Seismic Attributes of Fluids in Poorly Consolidated Sands
- P-203 - SNL-Partnership/David Aldridge - Inversion of Full Waveform Seismic Data for Three-Dimensional Elastic Parameters
- P-204 - LBL-Partnership/Valero Lorneev - High Speed 3-D Hybrid Elastic Seismic Modeling

- 00NT40832 - Prairie View A&M Univ./Innocent Aluka - Integrating P-Wave and S-sWave Seismic Data to Improve Characterization of Oil Reservoirs (funded through HBCU program)

1.4 Well Logging/Monitoring

- 96ER82159 Electromagnetics Instruments, Inc. - Oil Field Induction Resistivity Logging in Steel-Cased Wells (funded under SBIR)
- 99BC15201 Rice Univ./George Hirasaki - Fluid-Rock Characterization and Interactions in NMR Well Logging
- P-87 LANL - Partnership/James Albright - Fluid Identification Acoustic Logging Tool (funded under RLE forum)
- P-100 LANL - Partnership/James Albright - Formation Logging Tools for Microholes (funded under RLE forum)

2.0 RESERVOIR DESCRIPTION

- 00BC15309 Univ. of Tulsa/Dean Oliver - Mapping of Reservoir Properties and Facies Through Integration of Static and Dynamic Data
- 99BC15203 Southwest Research Institute/Jorge Parra - A Methodology to Integrate MR and Acoustic Measurements for Reservoir Characterization
- P-83 - LBL-Partnership/Don Vasco - High-Resolution Reservoir Characterization Using Seismic, Well and Dynamic Data (funded under RLE forum)
- P-102 LBL-Partnership/Mike Hoverston - Integrated Reservoir Monitoring Using Seismic and Crosswell Electromagnetics
- P-206-INEEL-Partnership/Tim Green - Locating Geopressure Hydrocarbon Reservoirs in Soft, Clastic Sediments Through the Identification of Associated Pressure Seals

2.1 Fracture Modeling

- 00BC15308 The Univ. of Texas at Austin/Jon Olsen - Advanced Technology for Predicting the Fluid Flow Attributes of Naturally Fractured Reservoirs from Quantitative Geologic Data Modeling
- 99BC15177 - Reservoir Engineering Research Institute/Abbas Firoozabadi - Research Program on Fractured Petroleum Reservoirs
- 98BC15100 Michigan Technological Univ./James Wood - Advanced Characterization of Fractured Reservoirs in Shallow Shelf Carbonate Rocks - The Michigan Basin
- 98BC15101 Golder Associates/William Dershowitz - Discrete Feature Approach for Heterogeneous Reservoir Production Enhancement
- FEW-A053 - LANL/James Albright - Advanced Seismic Geodiagnostics-Borehole Acoustic Source/Instrumentation for Fracture Mapping
- P-31 LLNL-Partnership/Steve Hunter - Advanced Tiltmeter Hydraulic Fracture Imaging Technology (funded under the OGRT forum)

2.2 Geomechanics

- FEW-4365 - SNL/Larry Costin - Geomechanics for Reservoir Management
- P-200-SNL-Partnership/Mike Stone - Coupled Geomechanical Deformation, Fluid Flow and Seismic

2.3 Core/Pore-Scale Studies

- 99BC15202 Texas A&M Univ.- Engineering Experiment Station/Ted Watsoh - NMR Characterizations of Heterogeneous Porous Media

- 99BC15204 - New Mexico Institute of Mining and Technology - Petroleum Recovery Research Center/Jill Buckley - Wettability and Imbibition; Microscopic Distribution of Wetting and its Consequences at the Core and Field Scales
- 99BC15205 - Univ. of Texas at Austin/Mukul Sharma - Characterization of Mixed Wettability at Different Scales and its Impact on Oil Recovery Efficiency
- 99BC15206 Univ. of Houston/Kishore Mohanty - Impact of Capillary and Bond Numbers on Relative Permeability
- 99BC15207 Purdue Research Foundation/Laura Pyrak-Nolte - Experimental Investigations of Relative Permeability Upscaling from the Micro-Scale to the Macro-Scale
- 00BC15306 Reservoir Engineering Research Institute/Abbas Firoozabadi - Wettability Alteration of Porous Media to Gas-Wetting for Improving Productivity and Injectivity in Gas-Liquid Flows
- FEW ESD99-001 - LBL/Liviu Tomutsa - Imaging, Modeling, Measurement and Scaling of Multiphase Flow Processes

2.4 Geostatistics

- 00BC15303 Univ. of Texas at Austin/Carlos Torres-Verdin - Integrated Approach for the Petrophysical Interpretation of Post- and Pre-Stack 3-D Seismic Data, Well-Log Ldata, Core Data, Geological Information and Reservoir Production Data via Bayasian Stochastic Inversion
- ACTI-065 - LANL-Partnership/George Zyvolski - Unstructured Grids for High Performance Reservoir Simulation/Innovative Gridding (funded under RLE forum)
- FEW-2266(P-32) PNL-Partnership/Mart Oostrom - Improved Prediction of Multiphase Flow in Petroleum Reservoirs

2.5 Basin-Specific - Multidisciplinary Studies

- 00BC15303 Univ. of Alabama/Ernest Mancini - Integrated Geologic-Engineering Model for Reef and Carbonate Shoal Reservoirs Associated with Paleohighs; Upper Jurassic Smackover Formation, Northern Gulf of Mexico
- 98BC15102 Univ. of Alaska, Fairbanks - Geophysical Institute/Wesley Wallace - The Influence of Fold and Fracture Development on Reservoir Behavior of the Lisburne Group of Northern Alaska
- 98BC15103 Utah Geological Survey/Craig Morgan - Reservoir Characterization of the Lower Green River Formation, SW Unita Basin, Utah
- 98BC15104 West Virginia Univ./Doug Patchen - Reservoir Characterization of Upper Devonian Gordon Sandstone, Jacksonburg-Stringtown Oilfield, NW West Virginia
- 98BC15105 Univ. of Texas at Austin-BEG/Charles Kerans - Integrated Outcrop and Subsurface Studies of the Interwell Environment of Carbonate Reservoirs: Clear Fork (Leonardian Age) Reservoirs, West Texas and Southeastern New Mexico
- 98BC15119 Clemson univ./James Castle - Quantitative Methods for Reservoir Characterization and Improved Recovery; Application to Heavy Oil Sands

3.0 RESERVOIR MODELING AND SIMULATION

3.1 Data Access

- 00BC15310 Univ. of Kansas Center for Research, Inc./Lynn Watney - Geo-Engineering Modeling Through Internet Informatics (GEMINI)

3.2 Data Preservation

- 99BC15115 American Geological Institute - National Geoscience Data Repository System-Phase III

- 00SW48306 National Academy of Sciences - Preservation of Geoscience Data and Collections

3.3 Field Laboratories

- 99BC15185 - University of Oklahoma/John Castagna - Gypsy Field Project in Reservoir Characterization

4.0 OIL EXPLORATION RESEARCH

4.1 Basinal Analysis

- 96BC14946 Univ. of Alabama/Ernest Mancini - Basin Analysis of the Mississippi Interior Salt Basin and Petroleum System Modeling of the Jurassic Smackover Formation, Eastern Gulf Coastal Plain
- 98BC15117 Univ. of Kansas/Tim Carr - Preparation of Northern Mid-Continent Petroleum Atlas
- 99BC15217 California Inst. of Technology/William Goddard - An Advanced Chemistry Basin Model for Petroleum Exploration
- FEW-P49398 ANL/Thomas Moore - The Use of Predictive Lithostratigraphy to Significantly Improve the Ability to Forecast Reservoir and Source Rocks
- FEW-4340-53 INEEL/Bruce Reynolds - Transportation of Hydrocarbon Indicators by Migrating Formation Waters in Selected Basins of the Four Corners Region
- FEW-FEAC310 ORNL/Bob Hatcher - Southern-Central Appalachians Framework and Controls of Hydrocarbon Generation

5.0 GENERAL

- 98BC15170 National Academy of Sciences/National Research Council - NRC Support to Board of Earth Sciences

B. DIAGNOSTICS AND IMAGING R&D IN THE GAS PROGRAM

Jim Ammer
National Energy Technology Laboratory

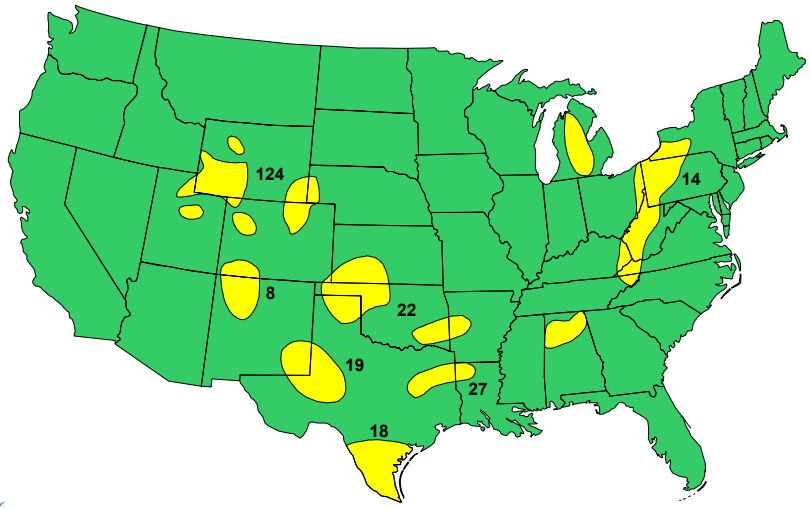
Diagnostics and Imaging R&D in the Gas Program

James R. Ammer
National Energy Technology Laboratory

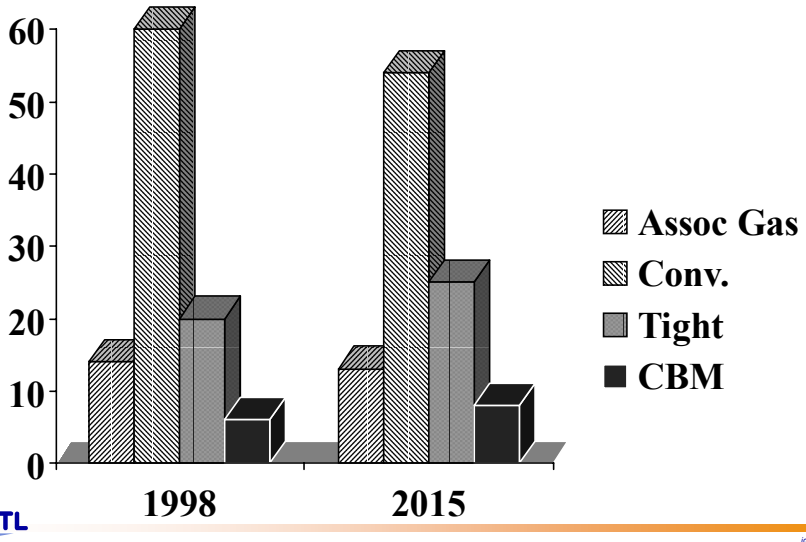
Gas Exploration, Production, and Storage Program Elements

- Drilling, Completion, Stimulation
- ➜**Low Perm Reservoirs/ Resource & Reserves**
- NGOTP
- ➜**Secondary Gas**
- Stripper Well Revitalization
- ➜**Gas Hydrates**
- Storage
- Technology Transfer

Location of Principal Nonconventional Gas Basins



NPC Projections of Nonconventional Production



Offshore Secondary Gas Recovery

- **GOM provides 25% of current U.S. production**
- **Contains 16% of proven gas reserves**
- **Most prolific Miocene-age strata in water depths <200 m amid existing infrastructure**
- **Mike Wiley - President & CEO, Baker Hughes**
  - Shallow water GOM deep geologic resources hold the greatest potential return on investment
  - deepest wells currently average 15,000 feet
  - major technology focus: new seismic methods, and advanced drilling and production

Hydrates Reserve Estimates

- **Worldwide:**
  - Oceanic: 30,000 to 50,000,000 Tcf
  - Continental: 5,000 to 12,000,000 Tcf
  - Compare to Conventional Gas Resource: 13,000 Tcf
- **Domestic:**
  - If 1% of hydrates are recoverable: 3,200 Tcf
  - Conventional Natural Gas Technically Recoverable Resource: 1,300 Tcf

Highlights of Past R&D

Major Focus - Natural Fracture Detection

identifier

Detection and Analysis of Naturally Fractured Gas Reservoirs (1992-1998)

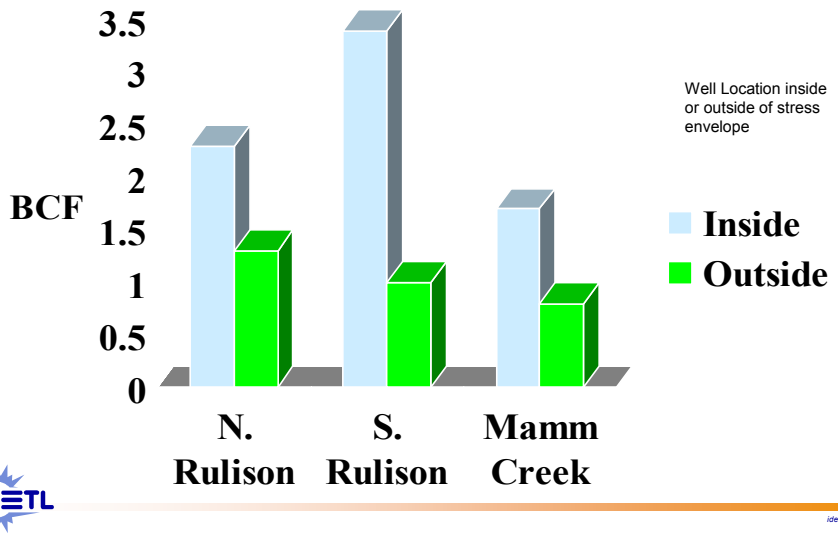
LBL	E. Majer	Anadarko Basin	Crosswell P-wave Theory
Stanford	G. Mavko	Powder River Basin	2D-P and 2D-S Theory
Blackhawk	R. Bates	Uinta Basin	2D-P and 2D-S VSP
ARI	V. Kuuskraa	Piceance Basin	3D-P 2 Azimuth Integrated Studies
Blackhawk	B. Grimm	Wind River Basin	3D-P Multi-Azimuth P-to-S
Sandia	J. Lorenz	Various	Field and Borehole Observations

identifier

Success Stories

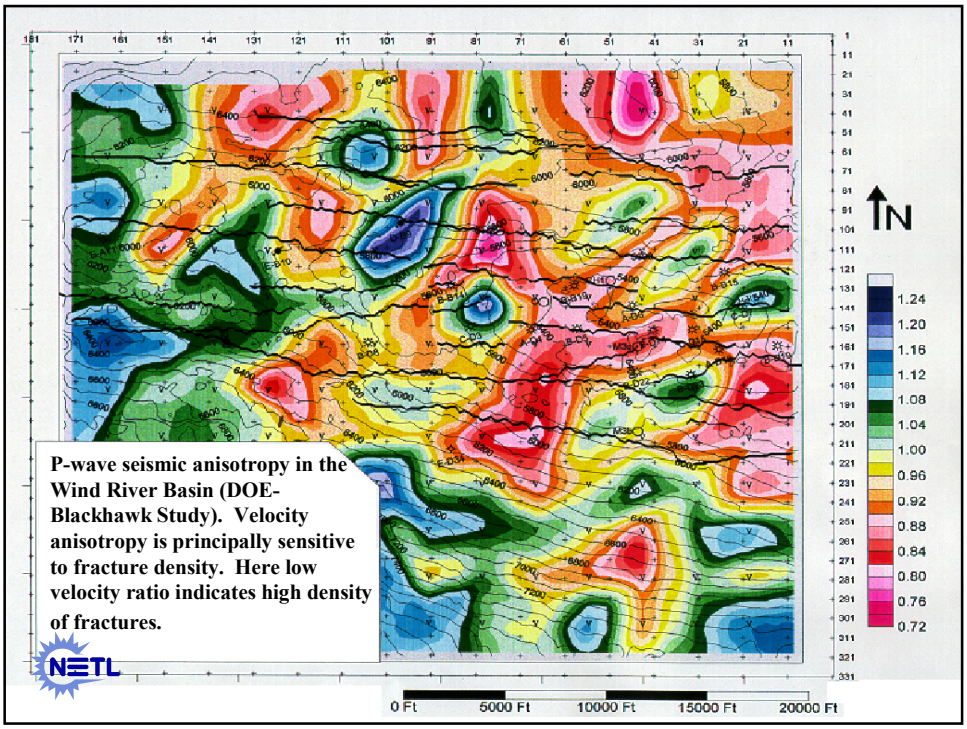
- **Geomechanical approach was validated for high-grading fault-related natural fracture sweet spots**
  - Existing production in Rulison field
  - Horizontal well step-outs in GGRB
- **Azimuthal dependent seismic attributes showed promise in delineating fracture density**
  - Correlated well with EUR (Wind River)
- **The success of these projects gave rationale for demonstration in exploration setting**

Rulison Field Fracture Detection Results



Geomechanical Modeling Applied to Horizontal Well Step-out

- **Project Specifics**
  - Union Pacific Resources (UPR) Company
  - Rock Island #4 Well drilled in Wyoming
  - Deep horizontal well (17,000 ft deep with 1,700 ft lateral)
  - Greater Green River Basin, Frontier formation (Tight Sand)
- **Results**
  - Production exceeded expectations (4.7 Bcf in 20 months)
  - Over 450 open natural fractures encountered
  - Based on well's success, two more wells were drilled



P-wave seismic anisotropy in the Wind River Basin (DOE-Blackhawk Study). Velocity anisotropy is principally sensitive to fracture density. Here low velocity ratio indicates high density of fractures.

Current

Diagnostics and Imaging

R&D

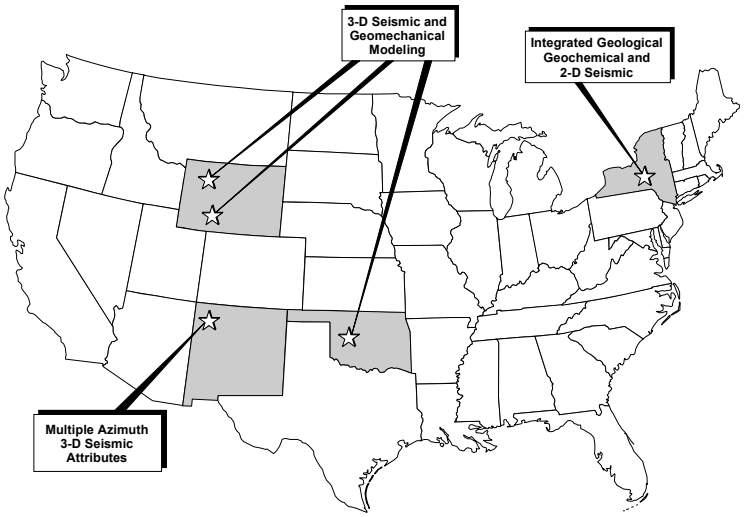
identifier

Natural Fracture Exploration

- Demonstrations in exploration setting
- Different geologic/basin settings
- Work with industry to promote acceptance

identifier

Natural Fracture Exploration



Geomechanical Modeling (ARI)

- **Predict fracture density due to fault-related deformation**
  - Calculate paleo-stress concentrations around fault systems using fault displacements
  - Delineate potential for fractures based on failure criteria
  - Calculate in-situ stress field around faults
- **Past work validated using EURs in Rulison Field and with horizontal well step-outs in GGRB**
- **Exploration validation in Anadarko Basin (Burlington) and Wind River Basin (Barrett)**

Multi-Attribute Study (GeoSpectrum)

- **Determine well prospect by integrating**
  - gas production data
  - fracture density data from core and FMI logs
  - multi-azimuth 3D seismic
- **Identify azimuthal variations related to fractures, focusing on p-wave anisotropy**
- **Evaluate curvature and frequency**
- **9 square miles in southern San Juan Basin (Burlington)**
- **Closely coordinated with LBNL and NMT studies**

identifier

Integrated Geophysics/Geology (SUNY)

- **Integrate low-cost methods to determine fractured plays at depth**
  - Structural/Outcrop studies locate FIDs
  - Aeromagnetics and remote sensing data are used to trace FIDs between outcrops
  - Soil gas anomalies confirm the lineaments are associated with fracturing
  - Well logs and seismic confirm interpretations at depth
- **Using 2D seismic vs. 3D**
- **Appalachian Basin (Quest Energy)**

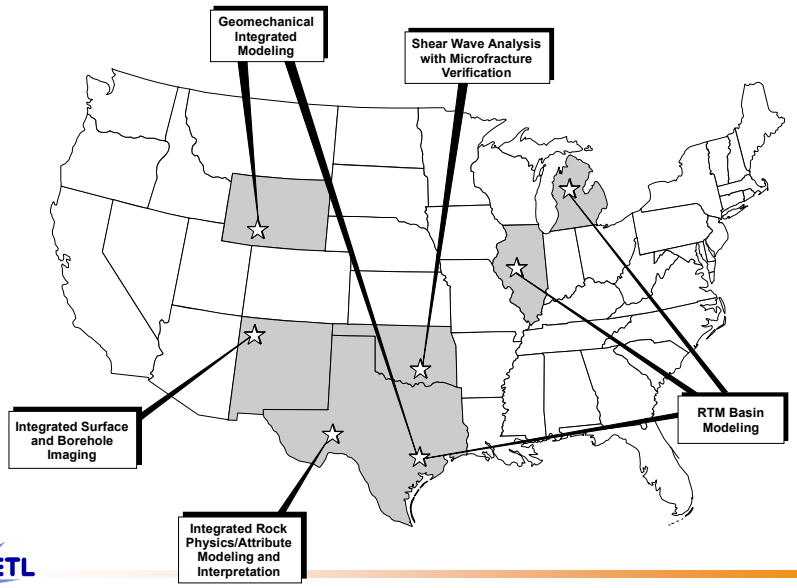
identifier

Next Generation Fracture Detection

- **Increase reliability and precision necessary to site wells**
- **Identify fracture properties**
  - fluid type
  - spacing
  - flow characteristics
- **Work with industry to promote acceptance**

identifier

Next Generation Fracture Detection



identifier

Theory and Methodology

Next Generation Fracture Detection

identifier

Integrated Surface and Borehole Imaging (LBNL)

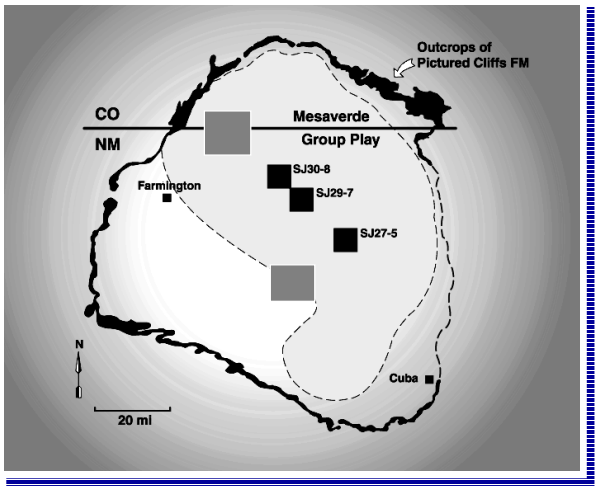
- **Develop and test seismic methods for fracture quantification**
  - Attribute analysis on existing 3D data
  - single-well seismic
  - VSP with 9 components
  - predictive modeling (geomechanical, seismic response of fractures)
- **20 square miles in NW San Juan Basin (Conoco)**
- **Players - LBNL, Schlumberger, Lynn Inc., Virginia Tech, Conoco**

identifier

Optimization of Infill Drilling (NMT)

- Develop methodology for optimum well spacing and patterns in naturally-fractured tight gas sands
- Major emphasis on understanding natural fracture orientation and anisotropy
- 3-D seismic data
  - seismic attributes
  - curvature
- San Juan Basin (BP, Burlington, Conoco, Williams Energy, Yates Petroleum)

Pilot Study Areas in San Juan Basin



Rock Physics/Attribute Modeling (Stanford)

- **Develop a new methodology for characterizing natural fracture properties**
  - rock physics theory/fundamentals of fracture response to seismic energy
  - high resolution seismic
- **Permian Basin of West Texas (Marathon)**
- **Spring 2001 field test - Walk-away VSPs and crosswell imaging in Yates field to obtain high resolution seismic attributes of fractured and unfractured portions of the reservoir**

identifier

Modeling and Analysis

Next Generation Fracture Detection

identifier

Integrated Modeling (ARI)

- **Develop an integrated modeling package to better predict fractured reservoir performance**
  - Geomechanical modeling
  - Discrete fracture network generation model
  - Reservoir simulator
- **Calibrate and validate using GGRB field data**
- **Field demonstration with industry in active drilling area (site and partner to be determined)**

identifier

S-Wave Propagation Analysis (BEG)

- **Combine a new shear wave imaging concept with micro-fracturing analysis for better detection and characterization of fractures**
  - 9C-3D seismic data
  - new data processing based on SH and SV mode
  - verify and calibrate using sidewall core microfracture analysis technique
- **Sycamore Limestone in Ardmore Basin, Oklahoma (Vecta Technology)**

identifier

Basin Modeling (Indiana University)

- **Use 3D seismic data to constrain 3D basin simulations to predict fracture locations and properties**
  - 3D Reaction-Transport-Mechanical Model
- **Illinois and Michigan Basins (New Albany and Antrim Shales) and Texas Gulf Coast (Austin Chalk)**
- **Players - Shell, Chevron, Texaco**

identifier

Offshore Secondary Gas Recovery (BEG)

- **Evaluate new techniques for defining structure, stratigraphy, and hydrocarbons to identify additional gas resources**
  - Interpretation Oriented Data Processing
    - Phase shift, Continuity, Spectral Balancing
  - 3-D Seismic Structural Framework
    - Fault Interpretation, Strata Surface Mapping
  - Seismic Attribute Analysis and Interpretation
    - Fluid Modeling, Seismic Lithology, Seismic Sedimentology using Stratal Slicing,
- **Starfak and Tiger Shoal Fields, Texas-Louisiana Shelf (Texaco)**

identifier

Gas Hydrate Characterization

- **Blake Ridge (U.WYO, UT Institute for Geophysics, NSF)**
  - High-resolution 3D seismic data to see stratigraphy, structure, gas, and gas migration pathways associated with free gas and hydrate
  - 3-component ocean-bottom seismometer data for first-ever P-S wave images of a hydrate deposit
- **Gulf of Mexico (UT Austin BEG)**
  - 3D 4-Component Ocean Bottom Cable data to improve detection of gas-hydrates
  - To develop integrated P- and S-wave imaging and interpretation technologies
  - Verify results with available well data

identifier

Summary of Diagnostics and Imaging R&D

- **Low Permeability/Natural Fracture Detection**
  - Exploration setting
    - Wind River, Anadarko, San Juan, Appalachian
  - Next generation fracture detection
    - Theory, Methodology, Processing, Modeling, and Analysis
- **Secondary Gas Recovery**
  - Structure and stratigraphy
- **Gas Hydrates**
  - Detection and characterization

identifier

C. NEXT-GENERATION SEISMIC MODELING AND IMAGING

Mike Fehler
Los Alamos National Laboratory

Next-Generation Seismic Modeling and Imaging

Participants:

- Industry (18)
  - Advanced Data Solutions, BHP Petroleum, BP, Burlington Resources, Chevron, Conoco, Exxon-Mobil, Fairfield/Golden, GECO-Prakla, Marathon, Paradigm Geophysical, PGS-Tensor, Phillips, Shell, Texaco, Union Pacific Resources, Unocal, Western Geophysical
- National Laboratories (2)
  - Los Alamos, Lawrence Livermore
- University (1)
  - Stanford University

Project Goals

- Build and test "next generation" elastic models (2-D and 3-D)
- Develop, test new 3-D wave-equation seismic imaging methods
- Finish migration of physical model data
- Close collaboration with industry and SEG to get results to participants quickly

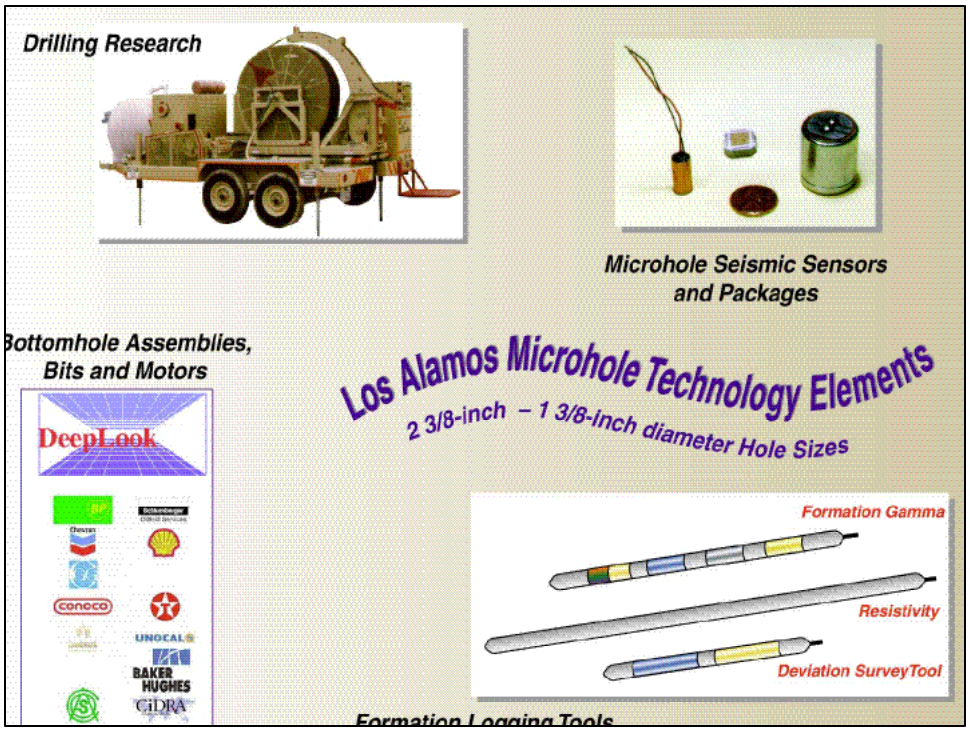
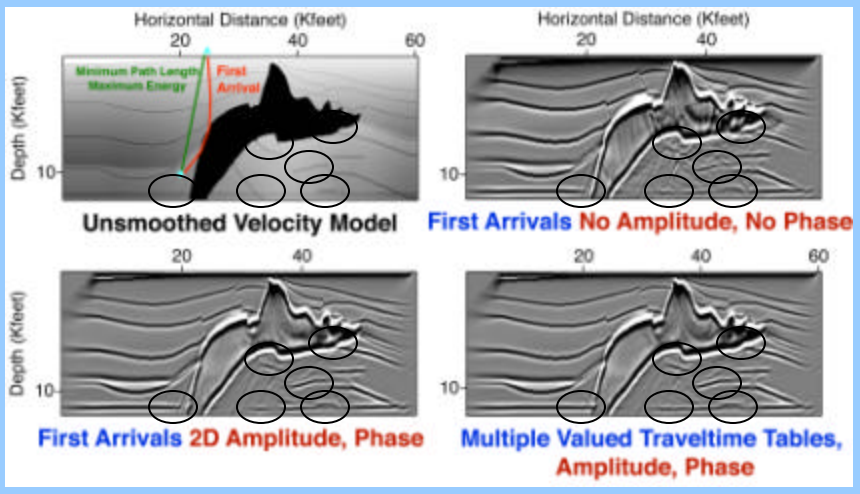
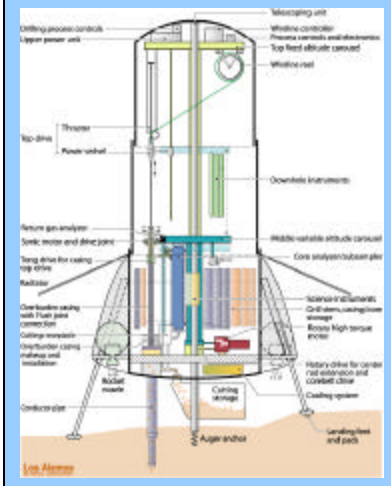


Image Comparison
O'Brien and Gray Numerical Pre Stack Dataset



SUBSURFACE SAMPLING CONCEPT FOR MARS 2007 LANDER



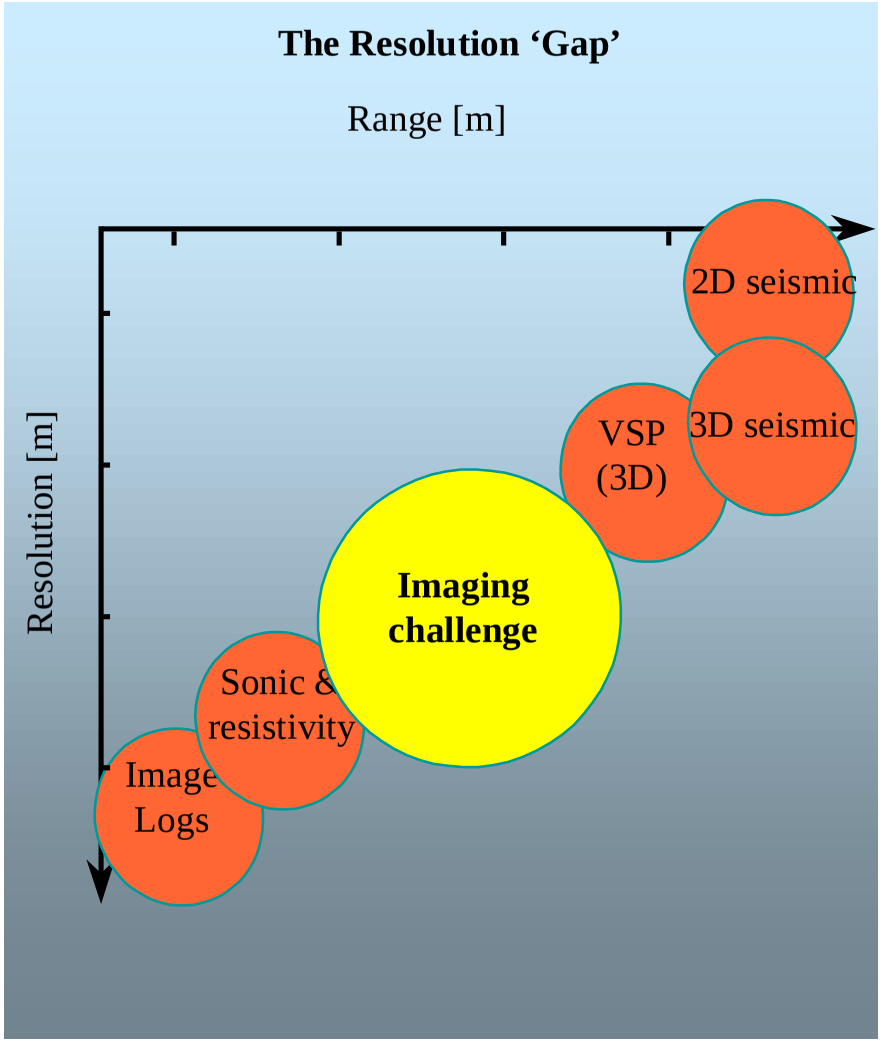
- **Hole stability provided by drilled-in casing at all depths**
- **Comminution by combined rotary-micropercussion drilling**
- **Cuttings removal by combined auger-sonification**
- **Samples in the form of fine-grained cuttings and continuous core**
- **Vertical, stabilized hole achieved by stepped diameter, concentric drill rod**

D. IMAGING & DIAGNOSTIC CHALLENGES

Richard Coates
Schlumberger

Imaging & Diagnostic Challenges

- Imaging Research Objectives
  - repeatability
    - "record and repair"
  - higher spatial resolution
    - single sensor seismic
    - borehole geophysics
  - timely answers
    - while-drilling measurements
  - calibration
    - "what does that change mean ?"



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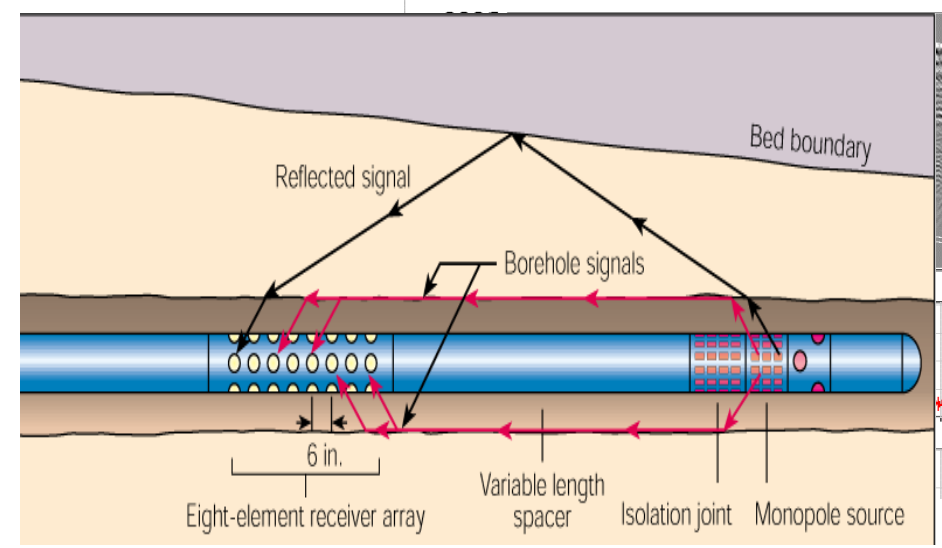
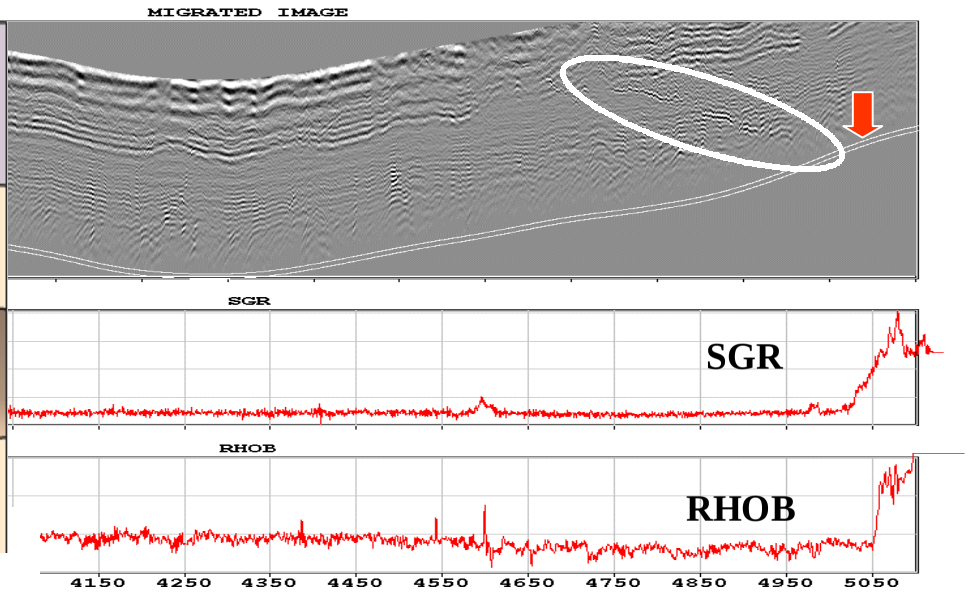
Single Well Sonic Imaging





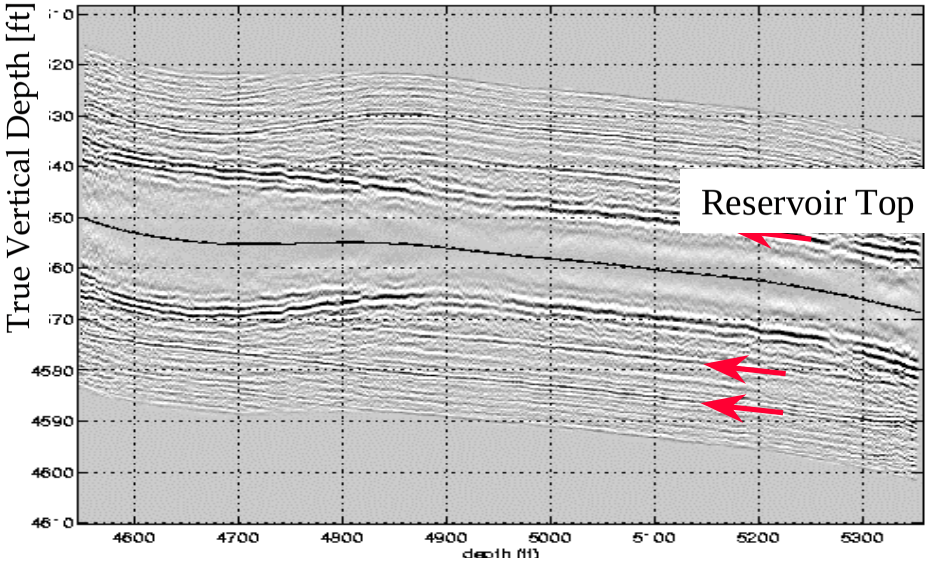


FIG. 2

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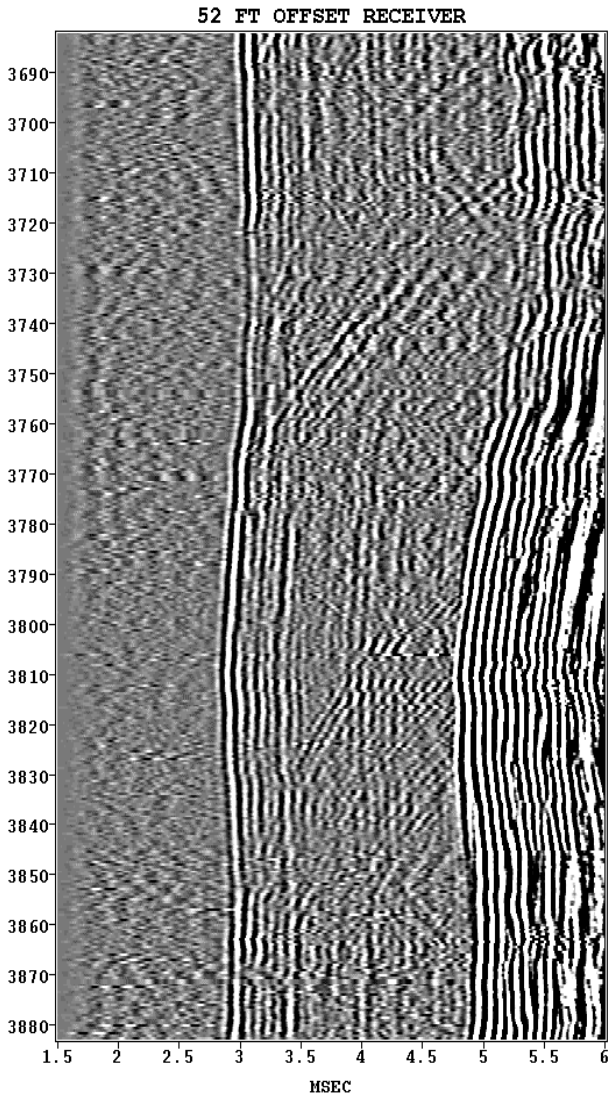
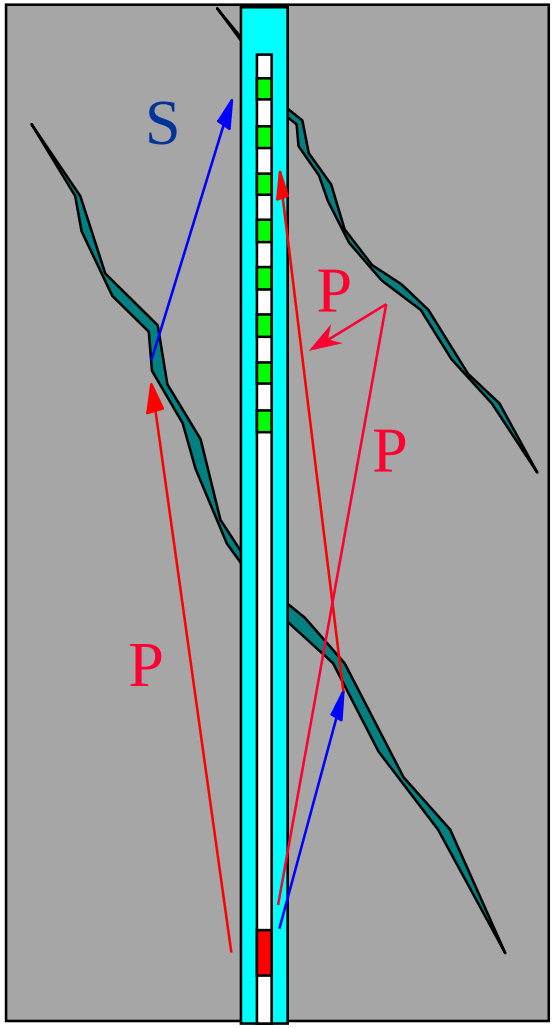
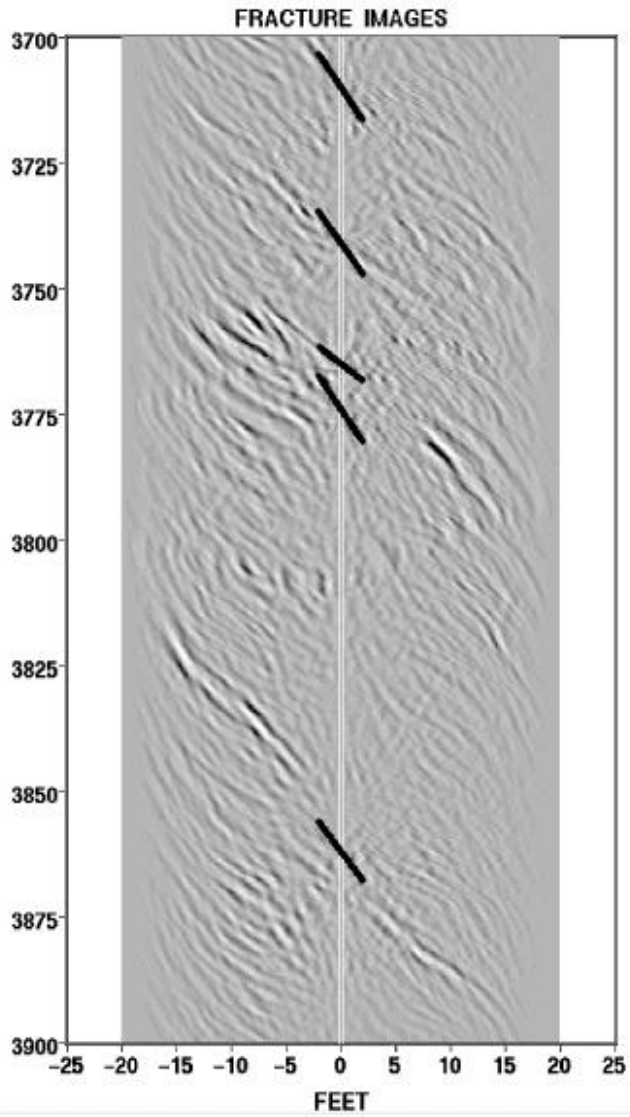
Field Examples: Fractures







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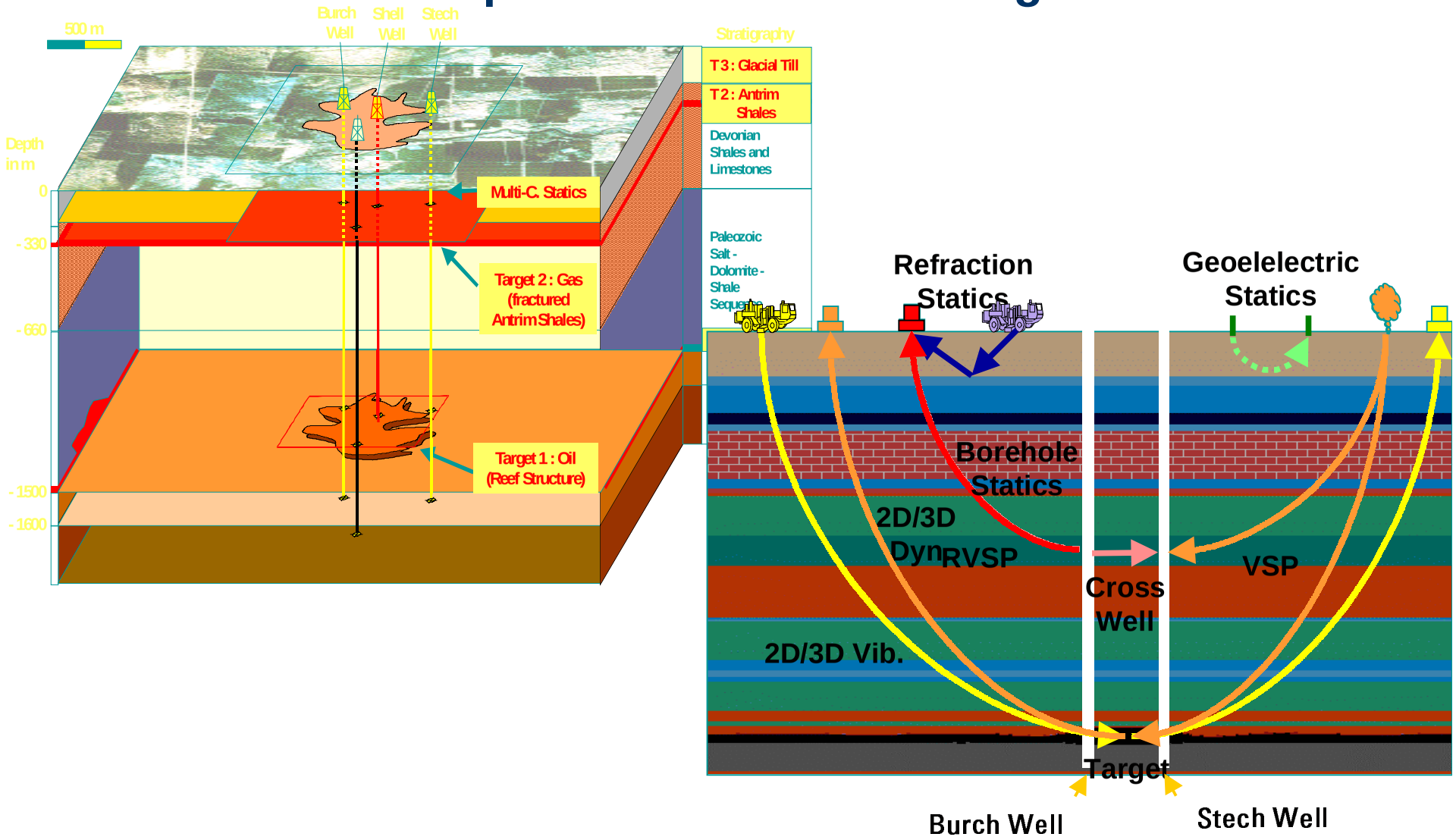
Integrated Surface & Borehole

Acquisition and Processing



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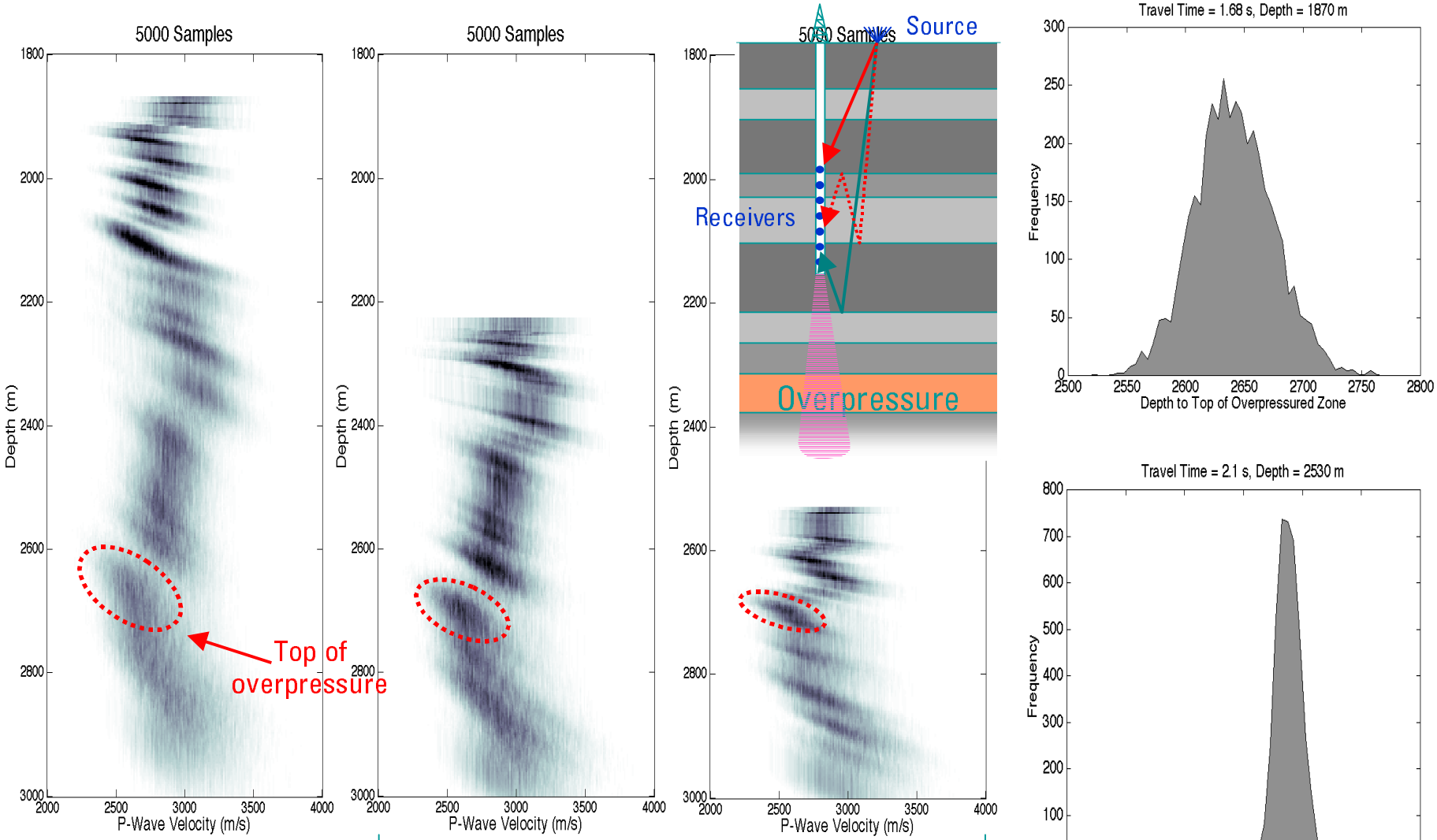
Seismic MWD



Schlumberger

II. INDUSTRY COMMENTS

ED STOESSEL, Retired BP
DeepLook consortium, which consists of 4 major oil companies and 6 service companies, focuses on identifying technologies to image reservoir fluids sufficiently for use in reservoir management. The use of coiled tubing to drill from existing wells is an excellent way of obtaining bypassed zones, but better imaging is needed to find these zones. Permanently instrumented wells to monitor fluid flow were discussed. The consortium funds pilot projects and subsequent phases as results dictate. One key is to look for technologies outside of the oil and gas industry.

ALAN HUFFMAN, Conoco
Conoco's diagnostics and imaging R&D effort is about $10 million annually. Emphasis is on multicomponent seismic, prestack inversion, advanced imaging methods, seismic analysis, geopressure prediction, and time-lapse seismology. The challenge is to keep a wide range of R&D. More collaborative efforts are needed to keep projects active in light of the number and size of projects. DOE's R&D funding should focus on the near term issues.

MIKE FEHLER, LANL
Among Los Alamos' Natural Gas and Oil Technology Partnership projects are next generation seismic modeling and imaging, Kirchoff imaging, Wave-equation migration, which is funded through the Office of Basic Energy Science, and microhole drilling.

RICHARD COATES, Schlumberger
(See presentation) Schlumberger's research effort is about $50 million annually. About 15 percent of this is for imaging research. Major issues include time-lapse repeatability, high spatial resolution, timely processing and calibration. One image challenge is bridging the gap between borehole logs and VSP/surface seismics. One focus is single well sonic imaging, which can see tens of feet away from the borehole with 1-foot resolution, another is seismic MWD.

MICHAEL HUDEC, University of Texas at Austin
There are two major avenues of research at the Bureau of Economic Geology related to Diagnostics and Imaging. The first of these is in acquisition, processing and interpretation of shear wave data. Results to date show that this technology can be an effective tool for mapping fracture orientations. The second theme involves best practices for 3D seismic interpretation. Current work focuses on 3D visualization, stratal slicing, and the use of neural net transforms to aid in interpretation.

CHRIS CORCORAN, Shell
Over the past few years, the oil and gas industry has experienced a reduction in labs and R&D funding causing a loss of critical mass in many key technology areas. More collaboration is needed, especially with the universities and national labs. Globalization is requiring new ways of working. The rapidly changing Information Technology environment is making work processes faster and cheaper. Issues include multicomponent, time lapse, looking ahead of the bit, and higher resolution from surface seismic (obtaining 3-10 meter resolution). Significant challenges include complex velocity regions (sub-salt, sub-basalt, fold belts) and ultra-deep (losing bandwidth).

J. (JOCK) DRUMMOND, Anadarko Petroleum Corporation
Anadarko has no internal R&D organization. Its annual research budget, of approximately $10 million, supports projects with universities, consortia, and private research companies. Looking ahead of the bit, higher resolution by getting sources and receivers closer to the reservoir, time cycle, and full acoustic finite difference depth imaging are some of the major issues. One of the key areas of interest is in offshore 3D depth imaging which is extremely time consuming and expensive - how to use the data or get rid of unnecessary data is a key issue to obtaining a more correct depth image. Reservoir characterization is the ultimate goal. Understanding the relationship between seismic response and reservoir characteristics, e.g., attribute analysis, is a second area of great interest.

JOHN RANDOLPH, Burlington Resources
Burlington is a pure consumer of technology. The budget for external R&D projects must compete with the exploration and production portfolios. Burlington supports about a half dozen projects with an emphasis on near term applications for the production and development units within Burlington. Projects designed to improve the seismic toolset are also supported. Technology transfer/capture is critical to the independent.

DIAGNOSTIC & IMAGING WORKSHOP

APPENDIX A
WORK GROUP PRODUCTS

Diagnostics and Imaging Workshop
What Are Reservoir Targets Driving Core R&D?

LITHOLOGY	OTHERS	GEOLOGICAL SETTING
• Tight-gas sands • Deep water high-performance reservoirs • Shallow water deep reservoirs GOM • Fractured shale • Tight pressured cell in clastic • Unconsolidated reservoirs • Heavy oil/clastic reservoirs • Bitumen sands • Oil shale • Dunes • Thin carbonate stratigraphic traps • VUGGY carbonates • Reefs • Carbonate • CBM (coal bed methane)	• Fractured reservoirs • Sequestration target reservoirs • By-passed hydrocarbons • Flood front • Seismically transparent • Infill/development • HPHT (high pressure high temperature) • Gas hydrates	• Fold-belts • Sub-basalt • Sub-salt • Turtle structures • Reservoir segmentation/compartments • Fractured reservoirs • Growth faults • Channel sands • Diagenesis

Diagnostics and Imaging Workshop
What Are Barriers/Issues to Locate and Quantify?

BASIC PHYSICS	BASIC PHYSICS SUBGROUP SEISMIC TO FLUID LINK	TOOLS AND TECHNIQUES	BUSINESS DRIVERS
• Invisible reservoirs A.I. • Q attenuation • Illumination and aperture • Seismic resolution • Bandwidth • Complex velocity and anisotropy • Permeability • Land near surface • Low-gas saturation • Reservoir communication • Aquifer ID • Limited understanding of seismic to rock properties • Non-seismic methods • State of stress (wellbore stability) • Fracture imaging and detection • Processing capability • Passive seismic • Understanding wave propagation • Imaging below salt, basalt, etc. • Cased wells • Pressure generation mechanisms • Reservoir heterogeneity • Multiscale integration and analyze	• Fluid identification • Well-to-seismic calibration • Limited core data • Better HCI prediction tools • Better HCI detection tools • Reservoir models • Migration pathways • Ground-truth seismic	• Lack of smart wells • Velocity estimation • Visualization of models • Integration of results • Deep water OBC depth limitations • Data display optimization • Time lapse – Normalization – Repeatability • Electrical methods • Real-time modeling, measurement iterative adjustments • Shear wave seismic (direct and mode-converted) • Gravity/magnetics gradiometry (airborne) • Look-ahead acoustics • BH acquisition coupling while drilling • Single well acquisition • Improved logging tools • Integration techniques	• Interpretation cycle time • Technology transfer • Willingness to change • Access to producing wells • Communication interdisciplinary • Lack of commitment • Risk aversion • Land access • Cost $ • Manpower • Quantifying uncertainty • Demonstrating value • Value of information • Knowledge management • Permitting • Environment

Diagnostics and Imaging Workshop
What Are R&D Opportunities for Diagnostic and Imaging?

BASIC PHYSICS		TOOLS AND TECHNIQUES		BUSINESS DRIVERS
• Tools for shear wave imaging ✪✪✪✪✪ • Pre-stack inversion and elastic inversion ✪✪✪✪✪ • Attenuation (Q) studies in rocks at several scales ✪ • Q estimation and compensation in seismic • Advanced modeling tools for illumination analysis ✪ • Measure R_x /fluid properties • What are limits on seismic resolution (surface/near surface) ✪✪✪✪✪✪✪✪ • Design acquisition system for higher resolution ✪✪ • Velocity model building with anisotropy ✪✪✪ • Robust modeling tools for fractured media (full elastic) ✪✪✪	• Studies of pressure generating mechanisms • Physical and computer modeling of fluid percolation processes • Advanced wave equation migration including elastic ✪✪✪ • Basic studies of wave propagation • Multi-physics inversion (including uncertainty) ✪ • Understand physics of seismic attributes ✪✪ • Elastic inversion migration without velocity • True amplitude seismic in subsalt • Shear wave response to petrophysical rock and fluid properties and changes with production • Core/pore property measurement/modeling • Permeability measurement wellbore to seismic scale ✪ • Diagenesis prediction • True amplitude mapping beneath basalt ✪ • Elastic wave imaging • Fluid-rock interpretation under seismic and e/m fields	• Improved AVO techniques ✪ • Develop direct detection tools – gas, oil, H_2O ✪✪✪✪ • Seismic and logging and coring test facility • Developing inexpensive ways of deploying subsurface source and receivers ✪✪✪ • Improve autopickers → self-interpreting seismic • Improved pressure prediction/seismic ✪✪✪✪ • Integrate FMI/single well/ and conventional seismic ✪ • Automated data distillation • Near wellbore fluid movement sensing ✪✪ • Imaging around the bit ✪✪ • Advanced pattern recognition of raw seismic volumes – train the computer to scan – brain better than eye • 4D recording and imaging of vertical data ✪ • BM log tools for advanced seismic attributes – Q	• Multilateral smart well ✪✪✪ • Integrated seismic-EM 1-well imaging system ✪✪✪✪✪ • Data fusion dynamic and static ✪✪✪✪✪✪ • CO2 sequestration modeling including interaction monitoring • Micro-electric low voltage passive seismicity – reservoir monitor • Ocean-bottom sensors for long-term deployment in 2000-4000 meters water depth ✪	• Development of risk assessment tools for general use • Tools to easily quantify the value of incremental information to reduce uncertainty • Comprehensive case study data sets/earth models for accelerated learning by decision simulation ✪ • Cost-reduction for multicomponent seismic

✪ = Vote for priority topic

Diagnostics and Imaging Workshop
What Are Actions to Take Advantage of R&D Opportunities?

R&D Opportunity with Details	Actions Products Deliverables	Expertise	Schedule	Lead Roles Collaboration
• What are limits on seismic resolution surface/near surface? – Acquisition and processing – Hardware – Sampling Theory	• Stimulate interest workshop plus web community • Recommendations plan product – Measuring experiment – Employ deep source and cost effective recovery	• Information theory • Hardware and engineering • Rock physicists • Astronomers and submariners • Ware propagation and imaging • Interpreters • Mathematician, physicist, geophysicist (exploration & theoretical)	• Summer workshops with SEG • As soon as possible with SEG September meeting	• Coordinate with SEG
• Data fusion dynamic and static – Use/assimilate multiple data sources – Knowledge management – Visualization	• Leverage other industries, e.g., military, medical • Ultimate goal software for real-time reservoir management • Data set demonstration • Real-time modeling/simulation • Automated metadata and knowledge capture • Real-time data streaming • Assimilation from multiple conflicting sources • Mindmeld • QC tools and automation of techniques – quantification of uncertainty	• Data management • Artificial Intelligence • 4D visualization • Uncertainty theory	• Several years	• DOE Office of Science recommend • Software firm develops • Industry partner for data • Service company commercialization
• Pre-stack inversion and elastic inversion – 3 component data – Processing framework • Subset: Tools for shear wave imaging	• Cross discipline involvement • Modeling study • Combined P&S structural images • Structural image in complex velocity regimes • Possible physical model • Develop practical approaches • Presurvey planning shear wave • Rock properties volumes with uncertainties • 3D volume of P and S impedance	• Wave propagation • Rock physicists • Mathematicians	• 5-10 years • Short-term field and synthetic data set	• Research and end users • DOE/SEG partnership with industry
• Integrated seismic-EM 1-well imaging system – DeepLook	• Same system integration • Any interest in cross well • Case studies	• Wide range already involved • Interpreters	• $800K/each 3 years • 6 months - proposal	• DeepLook

DIAGNOSTIC & IMAGING WORKSHOP

APPENDIX B
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